



Green Propulsion Technologies for Advanced Air Transports

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Green Propulsion Technologies for Advanced Air Transports

- **Importance of aviation in the global economy**
- **NASA Aeronautics and subsonic transport research**
- **Why hybrid-electric propulsion?**
- **Enabling hybrid-electric propulsion for commercial transport aircraft – A NASA perspective**
- **NASA technologies for hybrid-electric propulsion**
- **Looking toward the future**



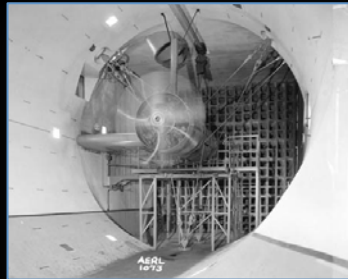
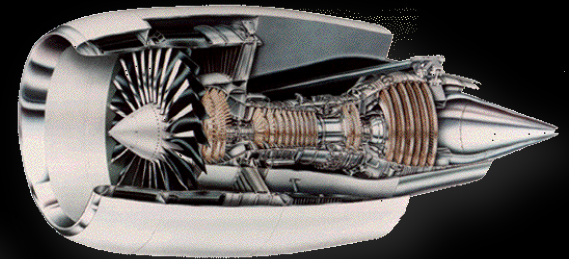
We have come a long ways, but we can go much further...



National Aeronautics and Space Administration



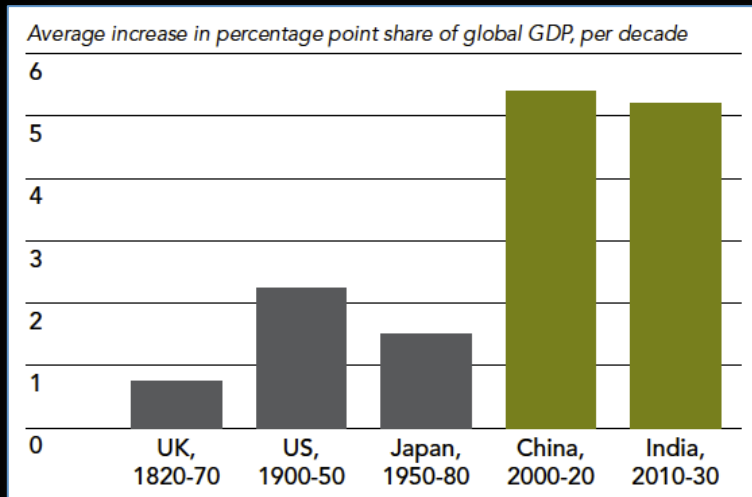
Remembering the Past



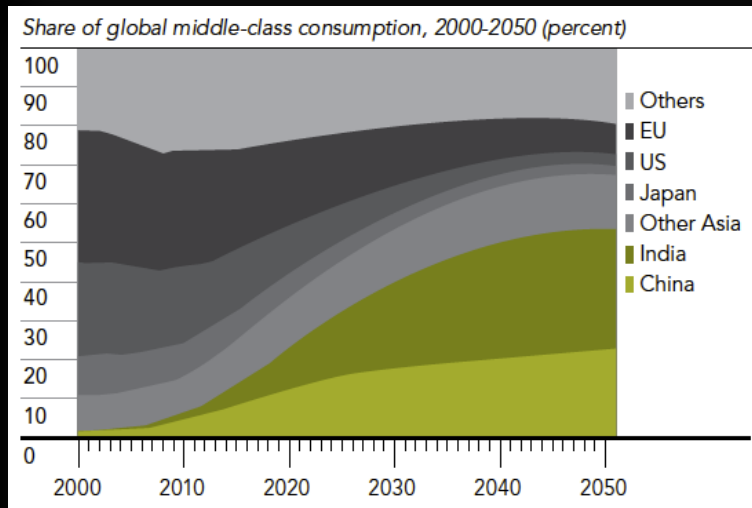


What do emerging global trends reveal?

New realities challenge traditional approaches to strategic planning.



China and India are growing economically at unprecedented rates

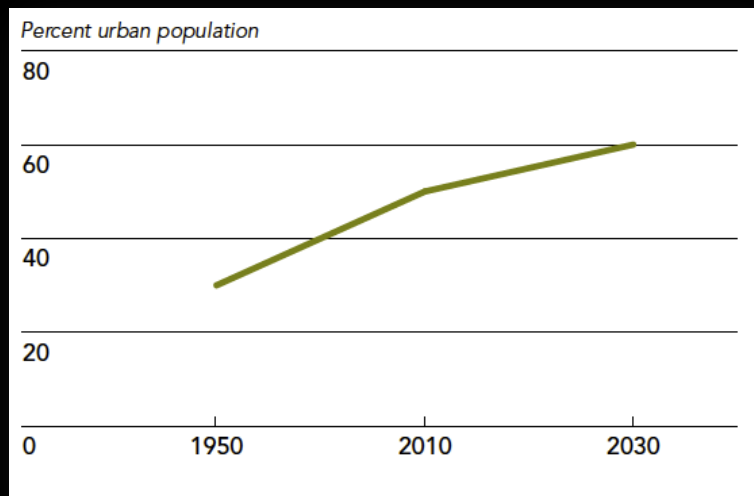


Asia-Pacific will have the largest middle class

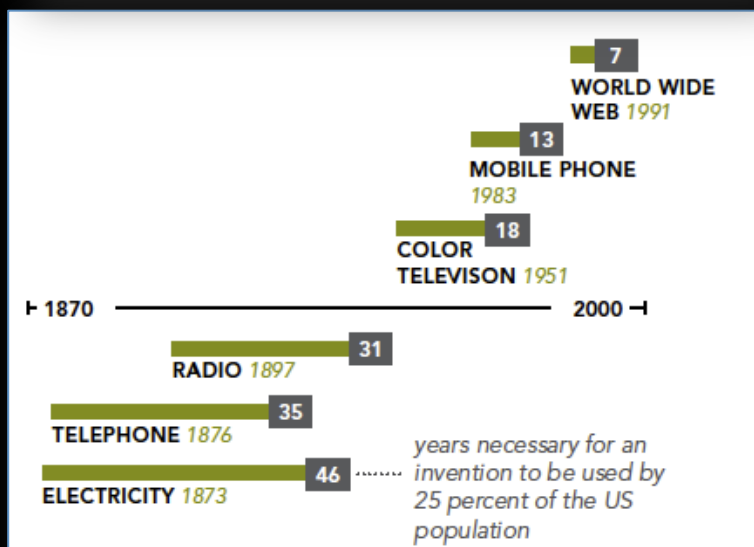


What do emerging global trends reveal?

New realities challenge traditional approaches to strategic planning.



The world will be predominantly urban

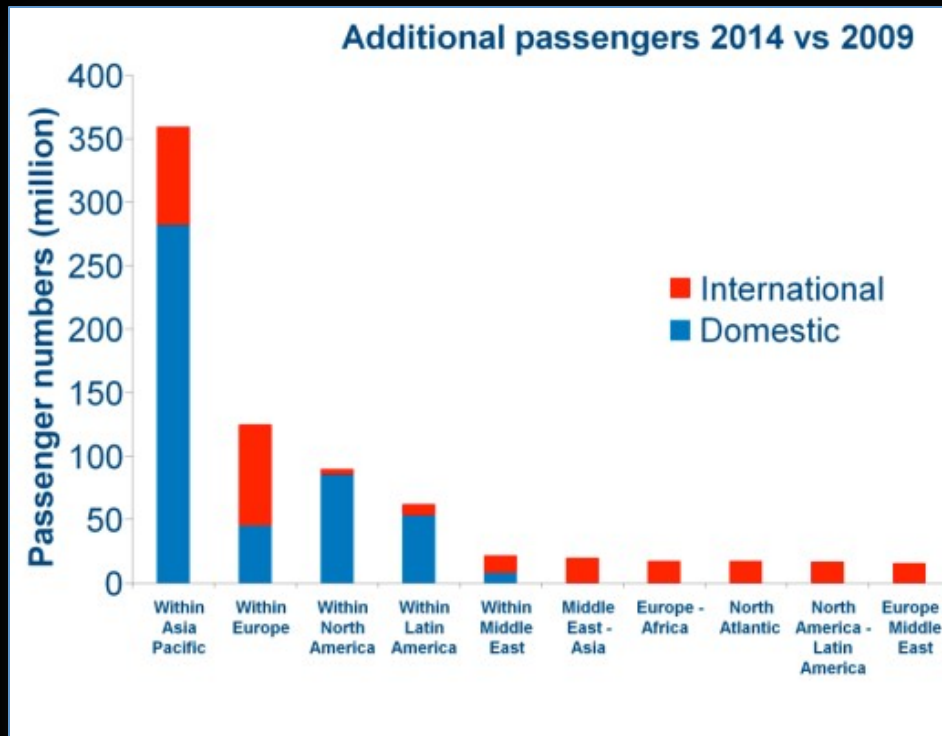


Revolutionary technology development and adoption are accelerating

Source: National Intelligence Council



Why are these trends important?



They drive global demand for air travel...

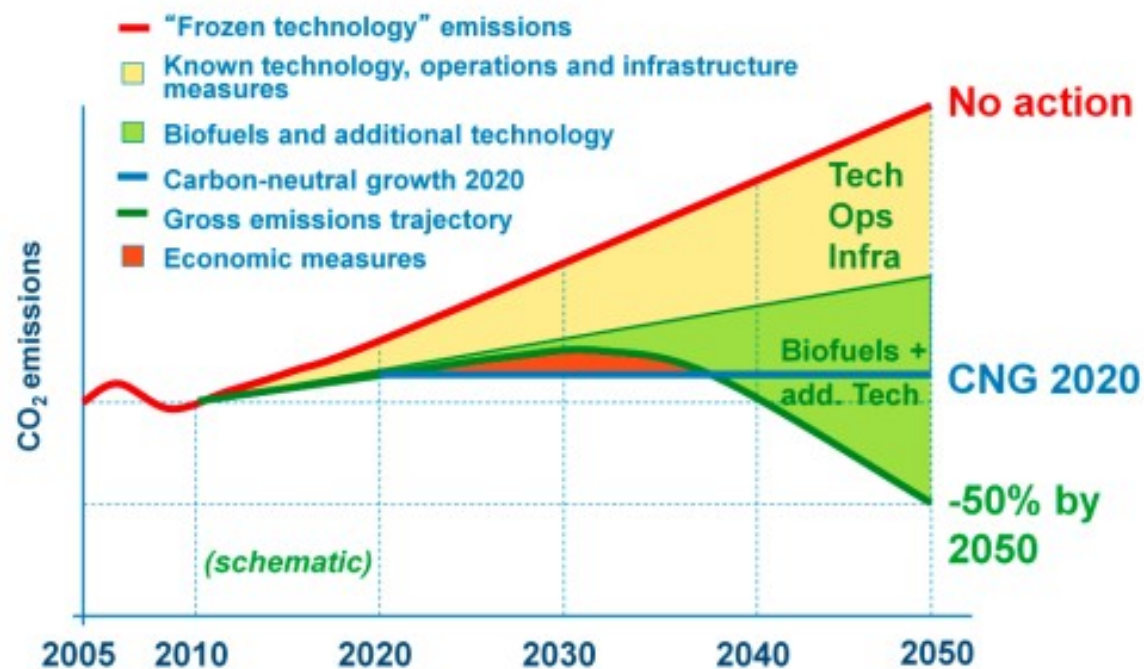
They drive expanding competition for high-tech manufacturing...

They drive “leapfrog” adoption of new technology and infrastructure...

They drive resource use, costs, constraints, and impacts...

They drive the need for alternative energy technologies...

Emissions reduction roadmap





NASA Aeronautics Vision for the 21st Century



**A revolution
in sustainable
global air
mobility**



NASA Is Responding With Its Aeronautics Mission

NASA Aeronautics focuses on six strategic R&T thrusts



Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard



Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance



Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology



Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system



Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications





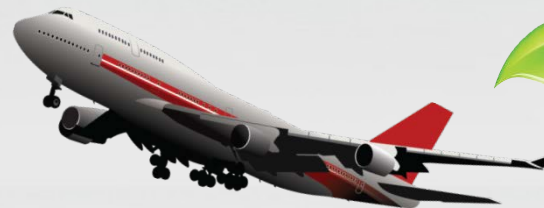
NASA Aeronautics Programs

Advanced Air
Vehicles
Program

Integrated
Aviation
Systems
Program

Airspace
Operations
and Safety
Program

Transformative
Aeronautics
Concept
Program





Advanced Air Vehicles Program

Cutting-edge research that will generate innovative concepts, technologies, capabilities & knowledge to enable revolutionary advances for a wide range of air vehicles

Advanced Air Transport Technology Project (AATT)

Conducts fundamental research to improve aircraft performance and minimize environmental impacts from subsonic air vehicles

Revolutionary Vertical Lift Technology Project (RVLT)

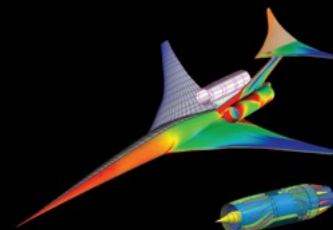
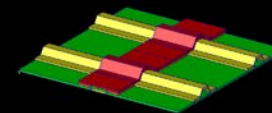
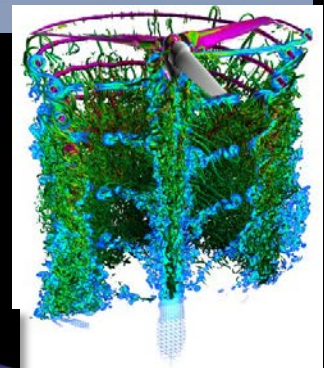
Develops and validates tools, technologies & concepts to overcome key barriers, including noise, efficiency, & safety for vertical lift vehicles

Advanced Composites Project (ACP) Conducts research to reduce the timeline for certification of composite structures for aviation

Commercial Supersonics Technology Project (CST) Explores theoretical research for potential advanced capabilities & configurations for low boom supersonic aircraft.

Aeronautical Evaluation & Test Capabilities Project (AETC)

Ensures the strategic availability, accessibility, & capability of a critical suite of aeronautics ground test facilities to meet Agency & national aeronautics testing needs





Advanced Air Transport Technology Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

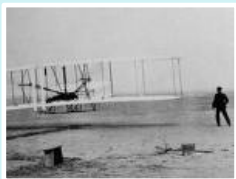
Vision

- " Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope

- " Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
- " Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility without adversely impacting safety
- " Development of tools as enablers for specific technologies and concepts

Evolution of Subsonic Transports



1903



1930s



1950s



2000s





NASA Subsonic Transport System-Level Metrics

Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility

v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption [‡] (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

Research addressing revolutionary far-term goals with opportunities for near-term impact



N+3 Advanced Vehicle Concept Studies Summary

Boeing, GE,
GA Tech



NG, RR, Tufts,
Sensis, Spirit



GE, Cessna,
GA Tech



MIT, Aurora,
P&W, Aerodyne



NASA,
VA Tech, GT



NASA



Trends:

- Tailored/multifunctional structures
- High aspect ratio/laminar/active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

Advances required on multiple fronts...



AATT Project Research Themes

Goals

Metrics (N+3)

Noise

Stage 4 – 52 dB cum

Emissions (LTO)

CAEP6 – 80%

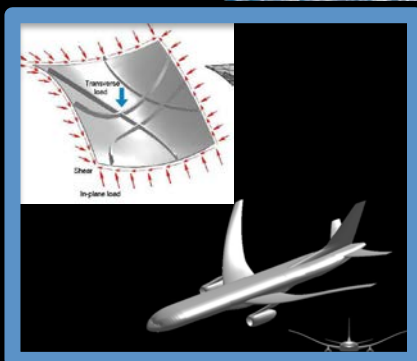
Emissions (cruise)

2005 best – 80%

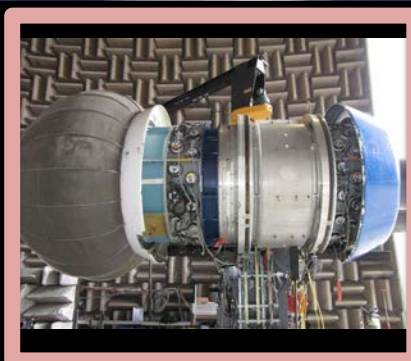
Energy Consumption

2005 best – 60%

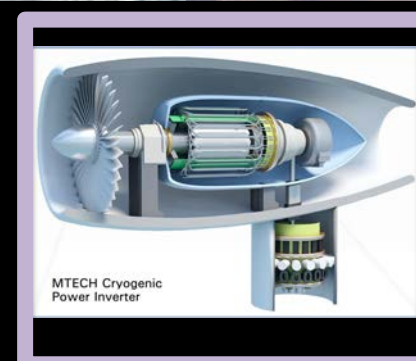
Goal-Driven Advanced Concepts (N+3)



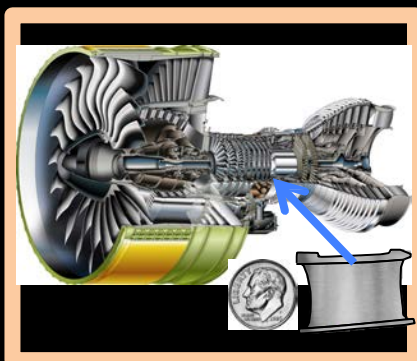
Lighter Weight
Fuselage and Wings



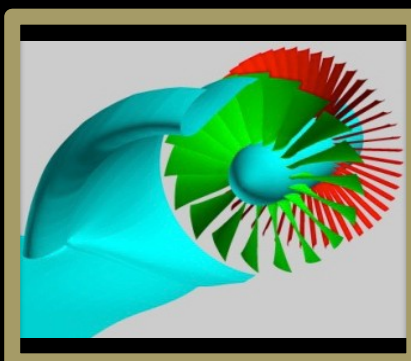
Noise Reduction
Technologies



Hybrid Gas Electric
Propulsion



Compact Higher
Bypass Propulsion



Propulsion Airframe
Integration



Alternative Fuels
Characterization



Electric Propulsion for Large Commercial Aircraft

- Why electric?
 - Fewer emissions (cleaner skies)
 - Less atmospheric heat release (less global warming)
 - Quieter flight (community and passenger comfort)
 - Better energy conservation (less dependence on fossil fuels)
 - More reliable systems (more efficiency and fewer delays)
- Considerable success in development of “all-electric” light GA aircraft and UAVs
- Creative ideas and technology advances needed to exploit full potential
- NASA can help accelerate key technologies in collaboration with OGAs, industry, and academia



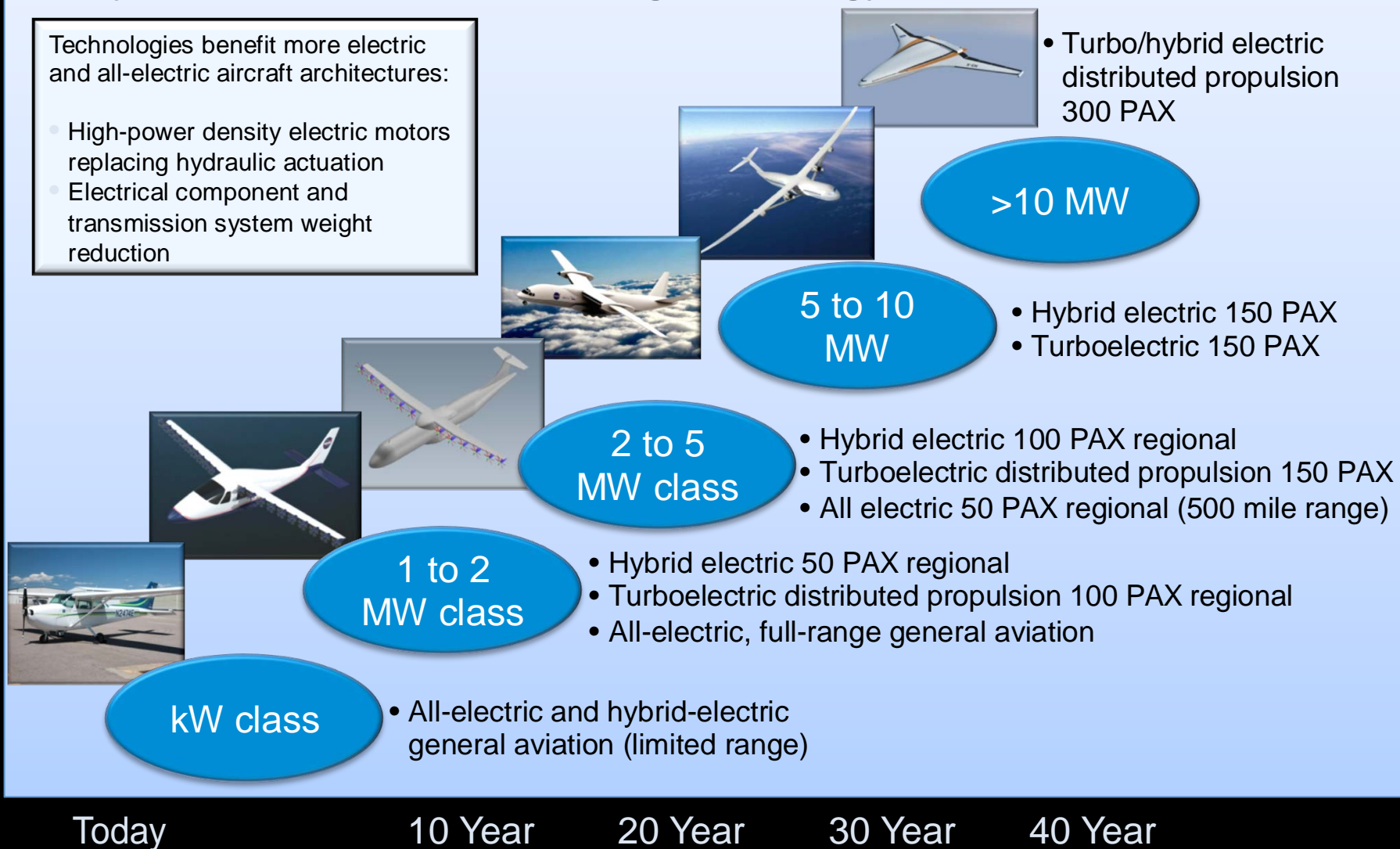
Aircraft Hybrid-Electric Propulsion

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Technologies benefit more electric and all-electric aircraft architectures:

- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

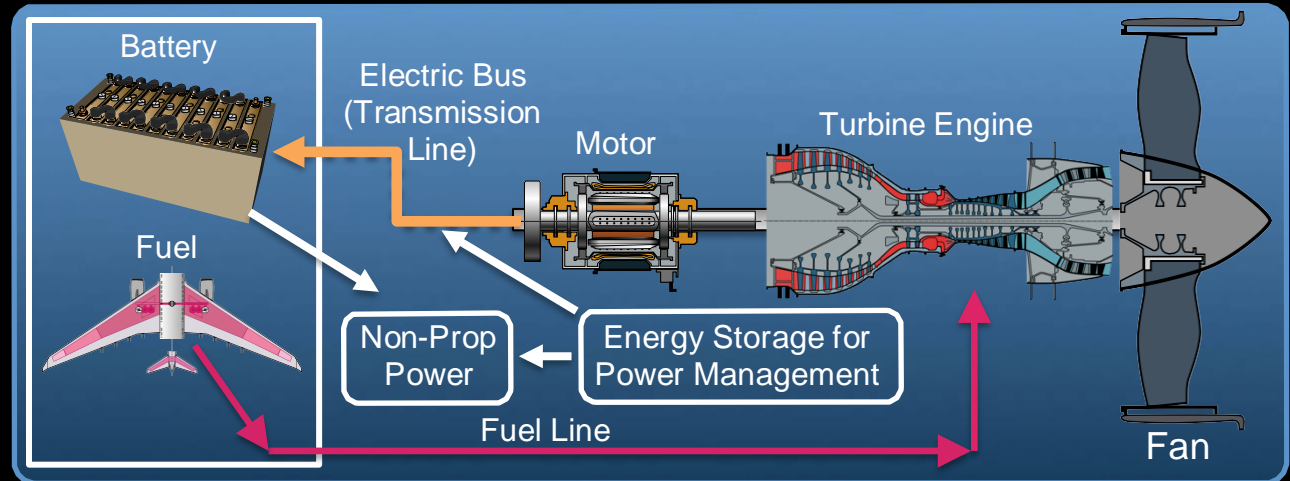
Power Level for Electrical Propulsion





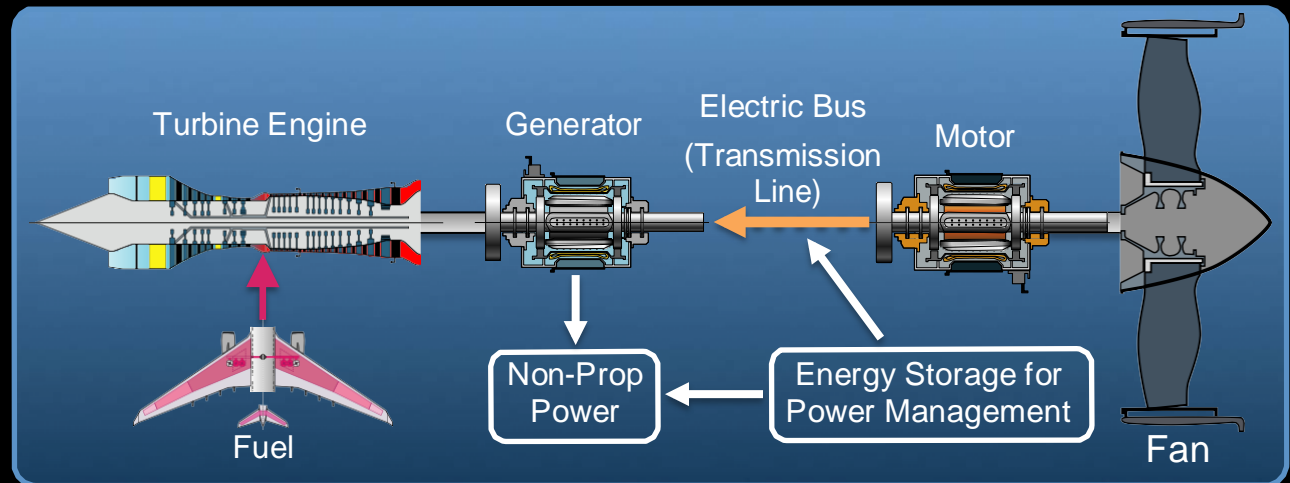
Possible Future Commercial Large Transport Aircraft

Hybrid Electric



Both concepts can use either non-cryogenic motors or cryogenic superconducting motors.

Turbo Electric





Estimated Benefits From Systems Studies

SUGAR (baseline Boeing 737–800)

- ~60% fuel burn reduction
- ~53% energy use reduction
- 77 to 87% reduction in NO_x
- 24-31 EPNdB cum noise reduction



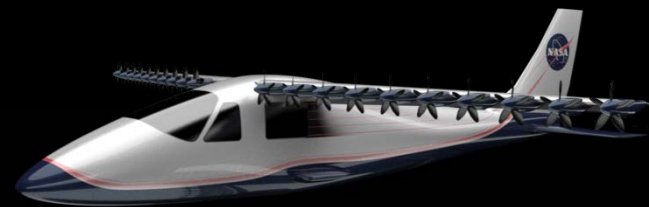
N3–X (baseline Boeing 777–200)

- ~63% energy use reduction
- ~90% NO_x reduction
- 32-64 EPNdB cum noise reduction

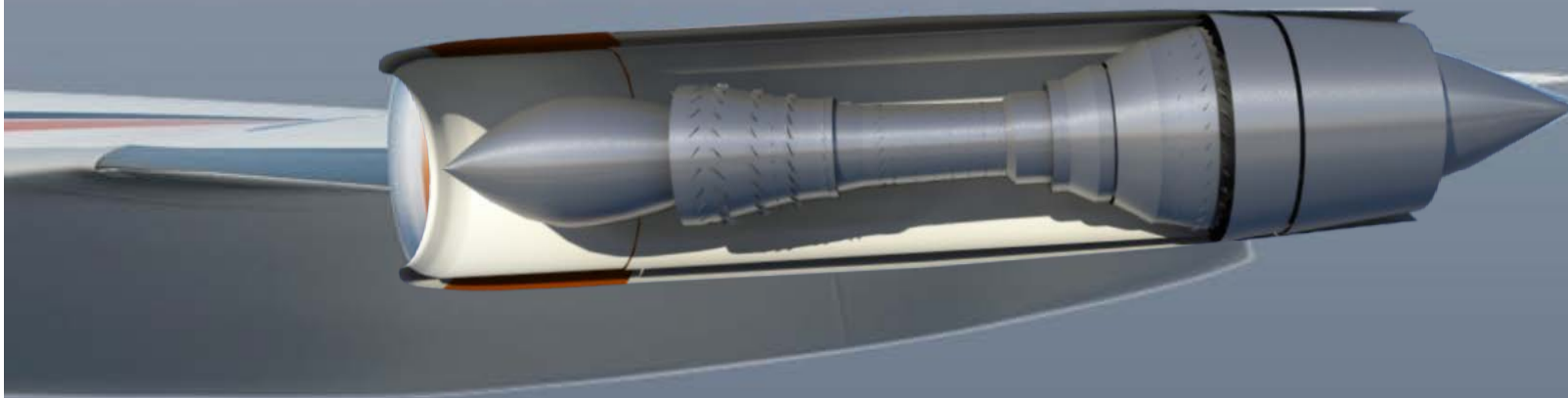


LEAPTech Wing Technology for GA (baseline Cirrus)

- 5 to 9x lower energy use/cost and emission
- 25 dB lower community noise
- Propulsion redundancy, improved ride quality, and control robustness



Technologies for Hybrid-Electric Aircraft

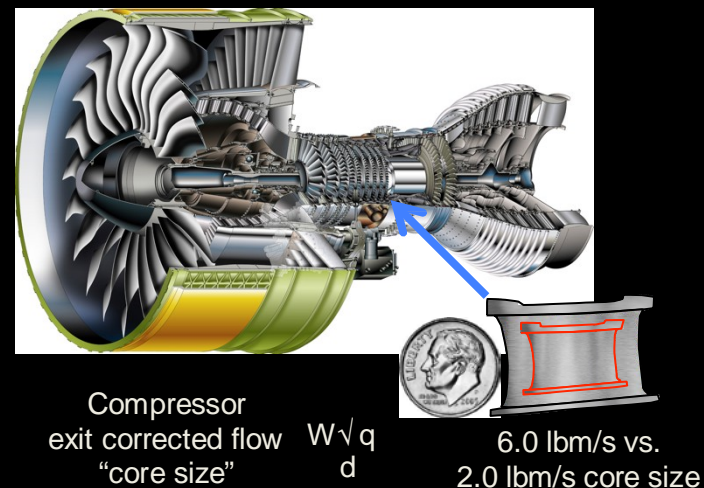




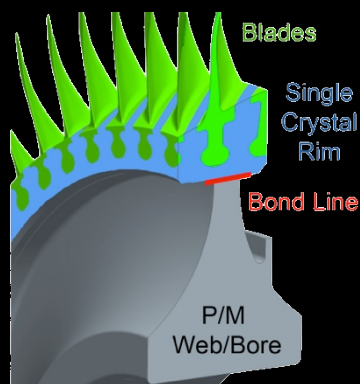
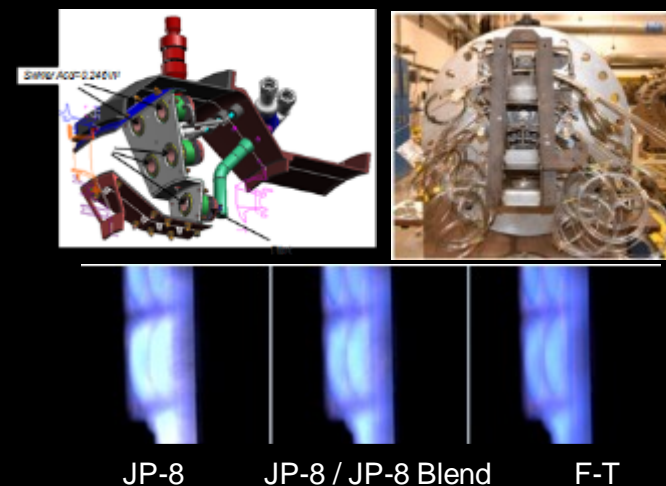
Highly Efficient Gas Generators

- 1500 °F capable disks, coatings, and non-contacting seals
- 2700 °F capable CMC turbine blades
- Low NOx fuel-flexible combustion
- Characterization of alternative fuels emissions
- Minimize losses due to large tip and hub seal cavity gaps of small size core
- Minimize cooling/leakage losses
- Assess system benefits and evaluate “smaller core” technology concepts for high-speed compressor demonstration

Smaller Core Size Research

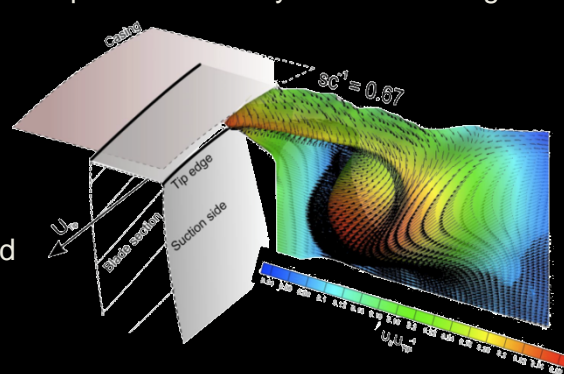


Low NOx , fuel flexible combustor

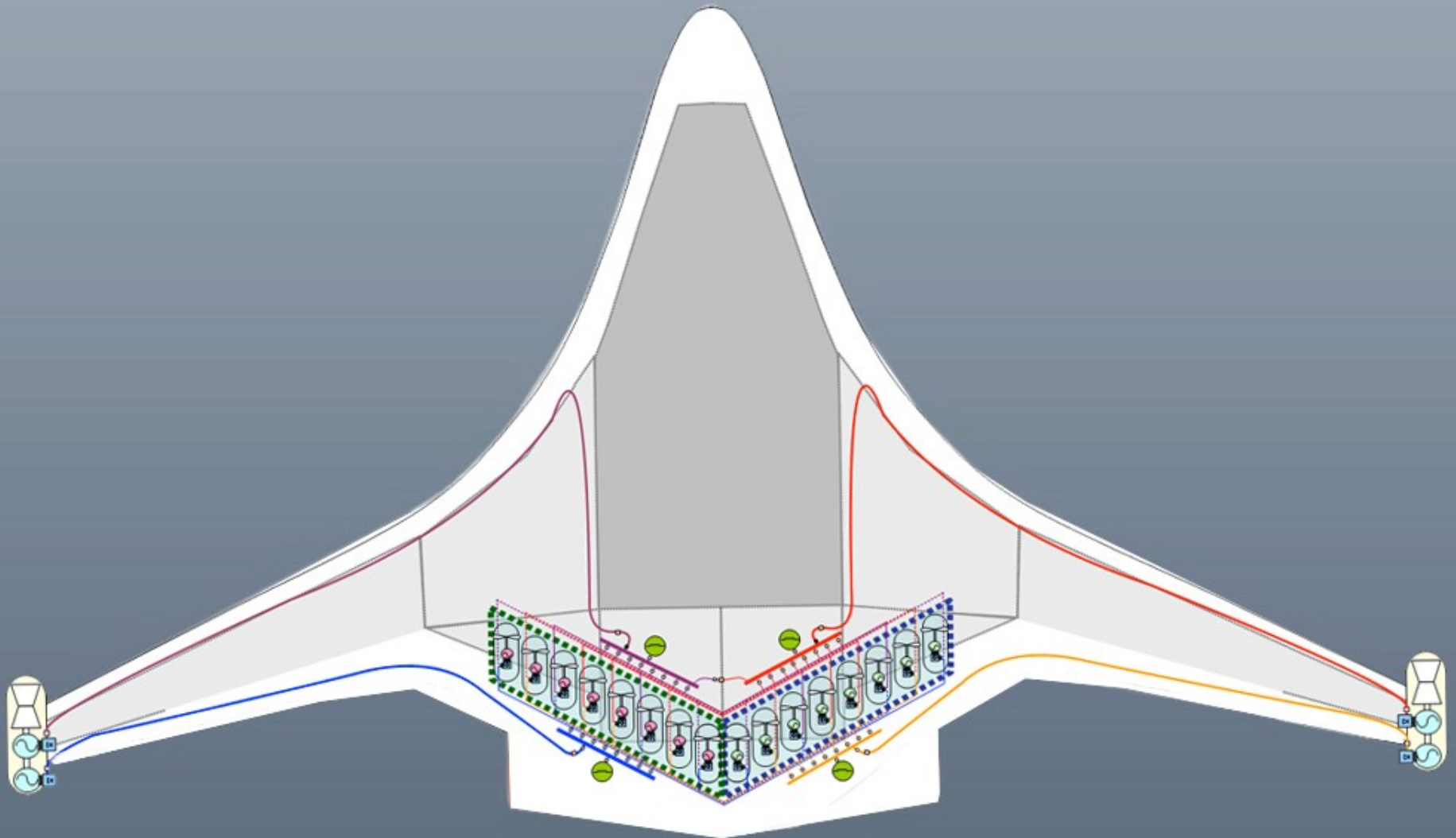


1500 F, bonded hybrid disk concept

Tip/endwall aerodynamic loss mitigation



Technologies for Hybrid-Electric Aircraft





Flight-weight Power Management and Electronics

- Multi-KV multi-MW aircraft propulsion power system architectures and associated control systems
- Power management, distribution and control at MW and subscale (kW) levels
- Integrated thermal management and motor control schemes
- Enabling materials and manufacturing technologies

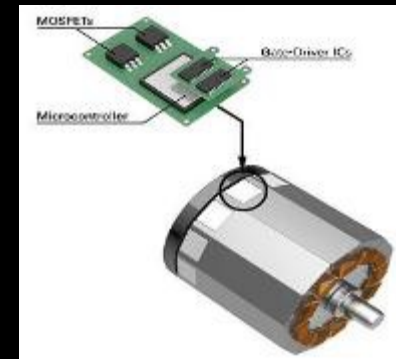
Superconducting transmission line



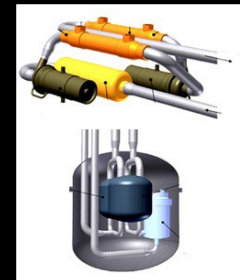
Lightweight power transmission



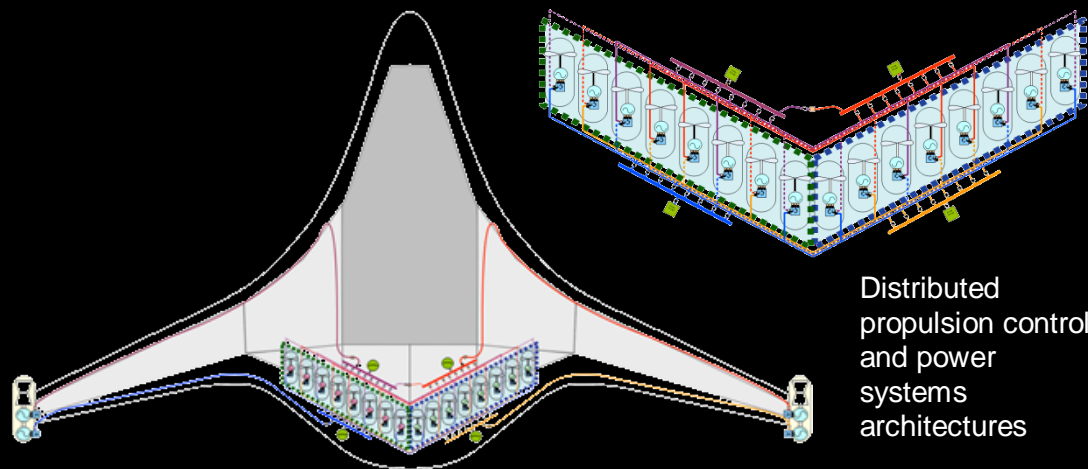
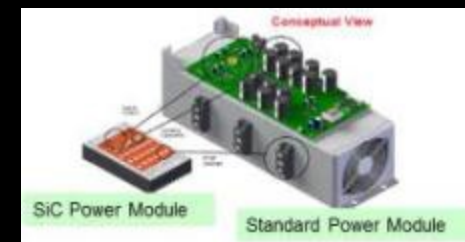
Integrated motor with high power density power electronics



Lightweight Cryocooler



Lightweight power electronics



Distributed propulsion control and power systems architectures

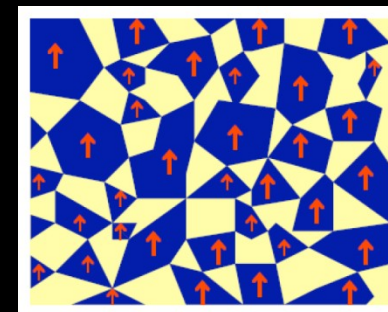


High-Power Density Electrical Motors

- Cryogenic, superconducting motors for long term
- Normal conductor motors for near and intermediate term
- High power to weight ratio is enabling
- Materials and manufacturing technologies advances required
- Design and test 1-MW noncryogenic electric motor starting in FY2015

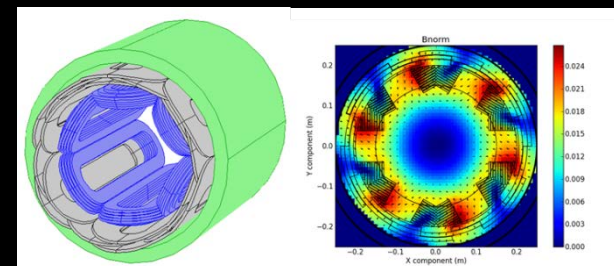
Nanoscale ultra-high strength low percent rare-earth composite magnets

High thermal conductivity stator coil insulation



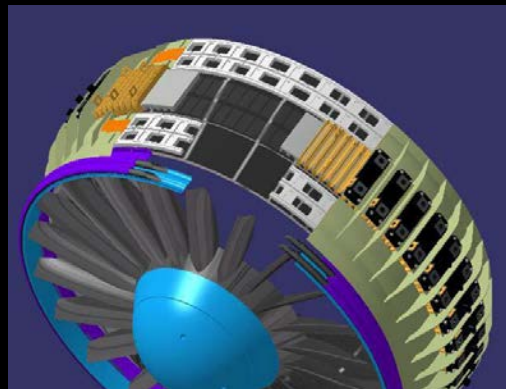
Superconducting electromagnetic model

Low A/C loss superconducting filament

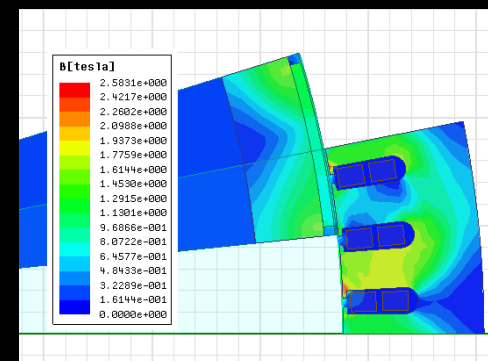
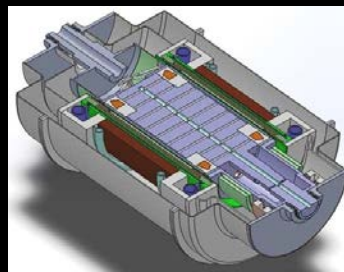


Flux density for rim-driven motor

Normal conductor 1-MW rim-driven motor/fan



Fully superconducting motor



Technologies for Hybrid-Electric Aircraft

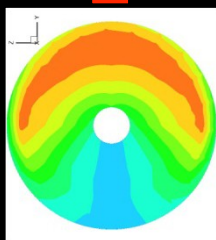
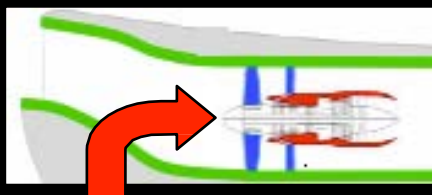
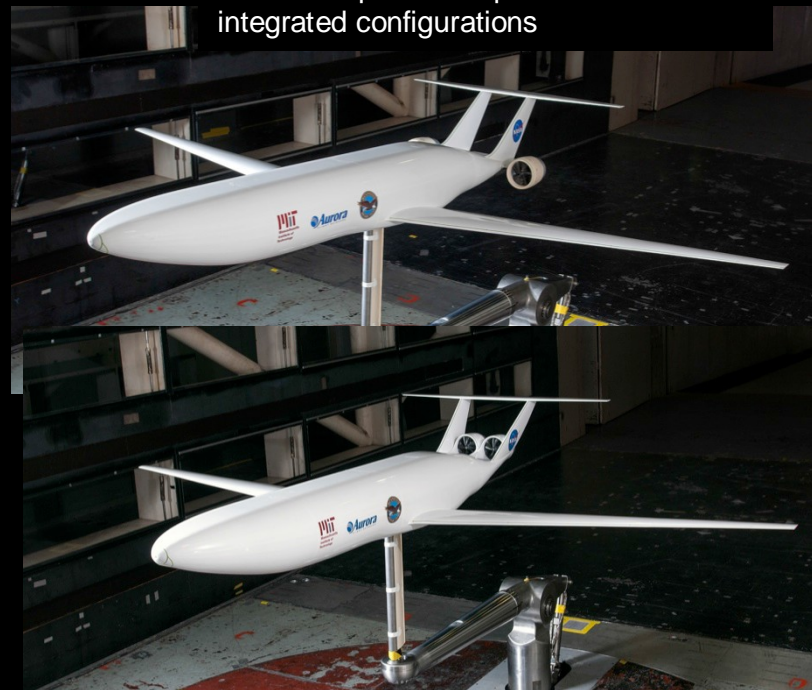




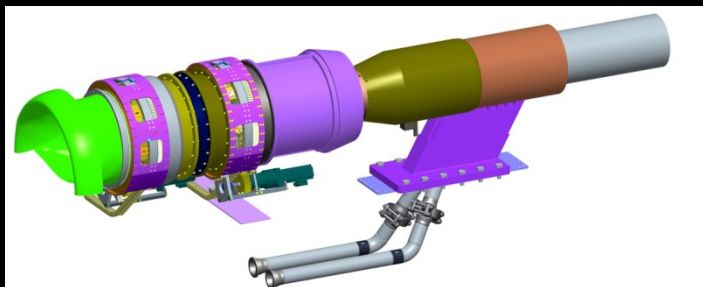
Understanding Boundary Layer Ingesting Systems

- Assess net system-level benefits of propulsion-airframe integration concepts relative to podded engines.
- Measure boundary layer ingestion benefits of integrated propulsion airframe configuration relative to podded engine.
- Design highly coupled inlet/fan tolerant to continuous operation in distorted inflow.
- Test performance of highly coupled inlet/fan design required to achieve net system level benefits.

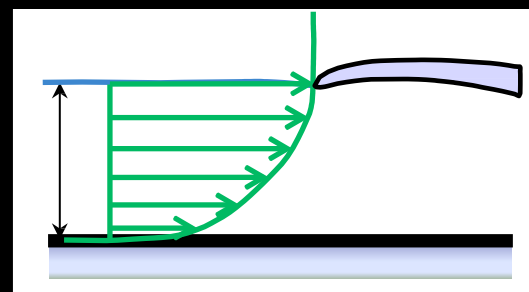
Direct comparison of podded and integrated configurations



Distortion tolerance required for net vehicle system benefit



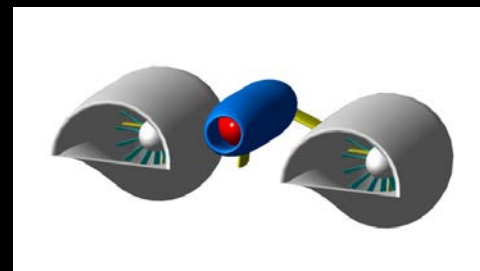
Reduced velocity in the boundary layer reduces inlet diffusion drag, but highly distorts inlet flow



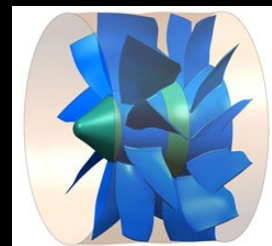


Efficient, Low Noise Propulsor Systems

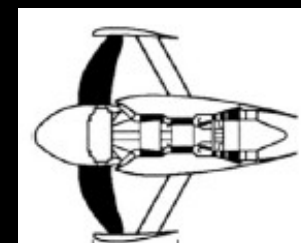
- Conceive and explore advanced propulsor architectures and technologies that alter the trajectory of noise and fuel burn trends for fans and open rotors to achieve future performance targets.
- Enhance analysis capabilities and acquire verification data to model nontraditional propulsion technologies and configurations.
- Maintain experimental facilities and capability to allow cutting-edge exploration of unique fan and open rotor system performance and associated physics.



Highly integrated, single core/motor, multiple propulsors



Counter-rotating fans



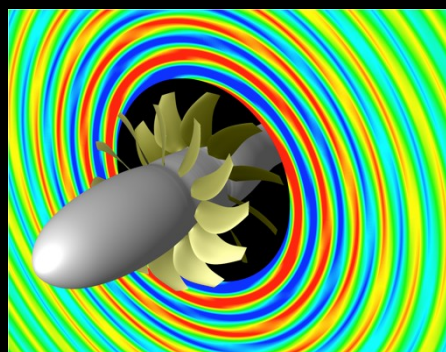
Shrouded open rotor concept

Nontraditional low noise technologies



Open rotor installed in NASA wind tunnel (2010)

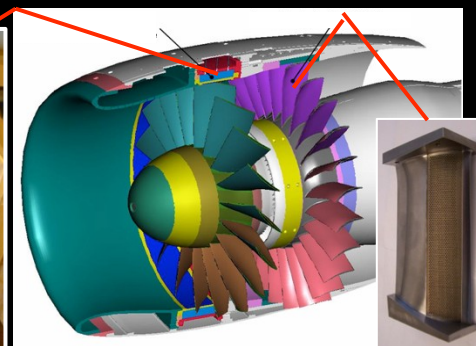
Open rotor noise prediction



Over-the-rotor acoustic treatment fan case



Acoustically treated "soft" vanes

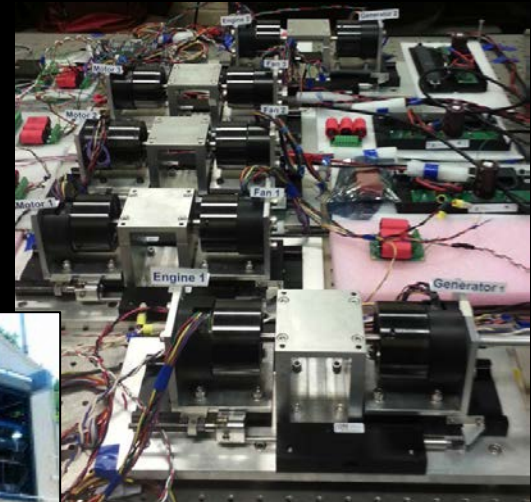




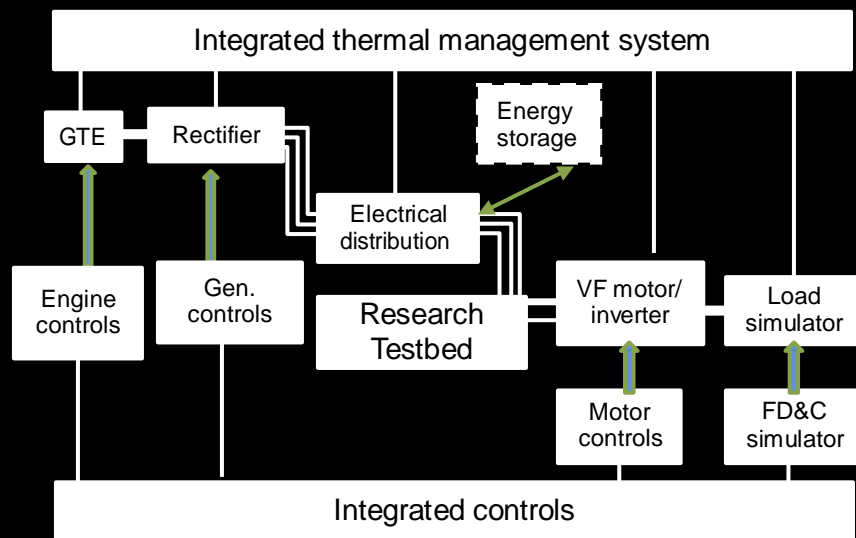
Enabling System Testing and Validation

- Develop MW-class power system testbed and modeling capability
- Demonstrate technology at appropriate scale for best research value
- Identify system-level issues early
- Integrate power, controls, and thermal management into system testing
- Develop validated tools and data that industry and future government projects can use for further development

Propulsion Electric Grid Simulator—hardware-in-the-loop electrical grid



Fully cryogenic motor testing
Glenn/SMIRF



Eventual flight simulation testing at NASA
Armstrong Flight Research Center

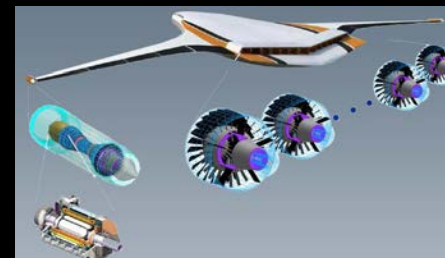




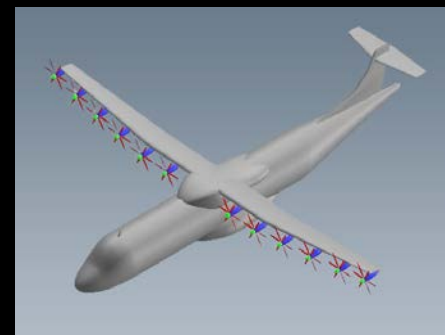
Integrated Vehicles and Concept Evaluations

- Determine design requirements and trade space for hybrid electric propulsion vehicles
- Identify near-term technologies that can benefit aircraft non-propulsive electric power
- Enhance analysis capabilities to model non-traditional vehicle configurations with HE systems
- Establish vehicle conceptual designs that span power requirements from GA (<1 MW) to regional jets (1-2 MW) to single-aisle transports (5-10 MW)

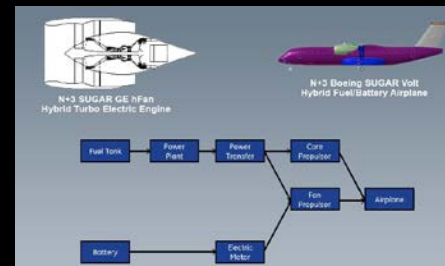
GTE/generator, distribution
& motor drive



Fully electric GA/
commuter



GTE and energy
storage (battery)





Looking to the Future...

- Exciting challenges for an industry that was deemed “mature”
- Conceptual designs and trade studies for electric-based concepts
- Tech development and demonstration for N+3 MW class aircraft
- Development of core technologies - turbine coupled motors, propulsion systems modeling, power architecture, power electronics, thermal management, and flight controls
- Multiplatform technology testbeds
- Development of multi-scale modeling and simulations tools
- Focus on future large regional jets and single aisle twin-engine aircraft for greatest impact

